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BOOTSTRAP METHOD OF ESTIMATING ACCURACY OF AN EFFECTIVENESS MEASURE IN FISH DETERRENCE

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Behavioural systems have been developed to deter fish from entering the intakes of nuclear generating stations. These systems include the pneumatic popper, air bubble curtain, strobe lights and combinations of the three. If found effective, these systems offer a less costly alternative to mechanical systems of excluding fish. In a recent study by EPRI, a measure of effectiveness called the percentage reduction for deterring fish was developed for these behavioural systems. At the request of the Biological Research Section of Chemical Research, measures of accuracy were attached to the percentage reduction values. A Monte Carlo simulation technique called the bootstrap method was applied to derive these measures of accuracy, the standard error and confidence interval. It was found that the popper device seems to successfully exclude fish more often than the other devices.

1. INTRODUCTION

Operational problems may arise due to fish impingement at generating stations. In order to reduce the impact of fish impingement, it was decided that effective barriers have to be developed. The Electrical Power Research Institute (EPRI) has studied the effectiveness of selected behavioural systems for fish deterrence at generating stations. There was evidence that these behavioural systems when used alone or in combination have been effective in limited field trials for attracting and repelling some species of fish. These behavioural systems are dependent on the innate behavioural responses of the fish to controlled stimuli such as light and sound. In the field trials these stimuli were generated by an air bubble curtain, the pneumatic popper, strobe lights and combinations of these. If effective, these behavioural systems offer a less costly alternative to mechanical systems of deterring fish.

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The Biological Research Section of the Chemical Research Department uses the percentage reduction as a measure of effectiveness for fish exclusion. This is defined as the difference in the mean fish catch between paired control and experimental structures divided by the mean fish catch in the control structure. The main objective of the present study was to attach a measure of accuracy to the percentage reduction estimator. The standard error and the confidence interval have been chosen to represent this measure.

The basic problem usually encountered when estimating standard errors of some unknown parameter is the absence of a classical method for estimation. Fortunately, in recent years computer-intensive simulations have become possible. One of these computer based techniques is the bootstrap method for estimating standard errors and confidence intervals. Furthermore, the method is not dependent on traditional parametric theory. This report discusses the bootstrapping method of estimating standard errors as well as confidence intervals for the percentage reduction measure.

2. THE DATA

There were four behavioural devices tested in 1985, and three additional ones in 1986, at the Pickering Nuclear Generating Station. These included the pneumatic popper, airbubble curtain, airbubble/popper and strobe lights/airbubble in 1985; the strobe/popper, strobe and strobe/airbubble/popper were added in 1986.

For both years, the experiments involving the popper and airbubbles were conducted in 13 or more field trials. The experiments involving strobe lights had limited trials of 4 or 5.

Two structures (east and west) were constructed at the water cooling intakes of the generating station for data collection. In the field trials, a behavioural device was fitted only at the west structure, leaving the east structure with no device for fish exclusion for some duration of time. The number of inshore and offshore moving fish caught were recorded simultaneously for both structures at a given time interval. When this was done, the next device was fitted until all devices were tried. The experiments were generally done at night time when fish movement was greatest. Additional control (no device) tests were conducted simultaneously for both structures to investigate any inherent differences in catch between the two structures.

3. THE STATISTICAL ANALYSIS

The effectiveness of a particular behavioural system for excluding fish from the nuclear intakes at the Pickering NGS is reflected by the magnitude of its associated percentage reduction, PR. The percentage reduction is:

$$PR = \frac{C - E}{C} 100$$

where C is the number of fish observed in the control (east) structure and E is the number of fish observed in the experimental (west) structure. If however, mean catch of fish in the east structure differs significantly from that in the west structure during control tests,

the mean catch in the experimental (west) structure, E, is corrected according to the formula:

$$E \frac{C_{east}}{C_{west}}$$

where C_{east} and C_{west} are the mean catch in the east and west structures, respectively, during control tests.

Table I summarizes the percentage reduction estimates (PR), for each deterrent used in 1985 and 1986.

The percentage reduction values of the pneumatic popper device are higher compared to the other devices. The air bubbles/popper device follows the popper device in this respect. Positive percentage reduction values for both these experiments may suggest a tendency for these deterrents to exclude fish. Since it is vital to first assess the accuracy of an estimator for decision making, the next concern is to establish this measure of accuracy.

Derivation of the standard error of the percentage reduction (PR) is difficult because its sampling distribution is unknown. Interest was instead focussed on an alternative way for estimation. A Monte Carlo simulation technique called the bootstrap offers a computer-intensive alternative for estimation of the standard error.

3.1 The Bootstrap Method

The bootstrap/1/ was used to assess the accuracy of the percentage reduction as an estimator. A general description of how the bootstrap works begins with having a random sample drawn from a target population. From this sample, a resampling is done several times to generate bootstrap samples which correspond to a random sample of size n with replacement. For each bootstrap sample, the percentage reduction is calculated. The standard deviation of this set of values correspond to the bootstrap estimate of the standard error.

A FORTRAN program was developed to run the Monte-Carlo algorithm that follow three steps:

i. Using a uniformly distributed random number generator, a large number (B) of boostrap samples are drawn independently.

ii. For each bootstrap sample, the percentage reduction value, denoted by P_i where i=1,2,3,... ,B, is evaluated.

iii. The sample standard deviation, $\hat{\sigma}_\beta$, of the percentage reduction values, P_i, is calculated using the formula:

$$\hat{\sigma}_{\beta} = \sqrt{\frac{\sum_{i=1}^{\beta} [P_i - P(.)]^2}{B - 1}} \qquad \text{where} \quad P(.) = \frac{\sum_{i=1}^{\beta} P_i}{B} \; .$$

Another measure used to assess the accuracy of the percentage reduction is the confidence interval. Two types of confidence intervals were used, the standard normal interval and one calculated by the percentile method. The standard normal interval gives a good confidence interval when the distribution of the estimate is approximately normal. Since for most devices, bootstrap distribution of the percentage reduction did not satisfy the normality assumption, a more accurate interval by percentile method was constructed. The percentile method/2/ of estimating confidence intervals is based on the distribution of the bootstrap estimate of the percentage reduction.

3.2 The Standard Normal Confidence Interval

The 95% standard normal confidence interval for the percentage reduction is defined as:

$$PR \pm \hat{\sigma}_{\beta} \, z_{\alpha/2}$$

where PR is the percentage reduction estimate of a deterrent, $\hat{\sigma}_{\beta}$ is the bootstrap estimate for the percentage reduction standard error and $z_{\alpha/2}$ is the 95% percentile point of the standard normal distribution.

3.3 The Percentile Method for the Confidence Interval

The 95% confidence interval for the percentage reduction using the percentile method was derived from the distribution of the percentage reduction bootstrap estimate. The lower limit and upper limit of the percentile method corresponds to the 2.5 percentile point and the 97.5 percentile point of the bootstrap distribution, respectively. This interval however, is centred around the bootstrap mean for the percentage reduction, P(.). Therefore, to centre the interval around the percentage reduction estimate (PR), an adjustment has to be made. The adjustment was made according to the formula:

$$D = PR - P(.)$$

where PR is the calculated percentage reduction from the original sample and P(.) is the bootstrap mean value of the percentage reduction. This difference is then added to both endpoints of the interval.

4. RESULTS

The bootstrap mean of the percentage reduction values from B = 500 samples, referred to as P(.) in the above notation are shown in Table II.

For the air bubble/popper, popper and air bubble experiments, the bootstrap mean is close to the percentage reduction value calculated from the original sample (See Table I & II). Discrepancies between the two estimates were observed in the last four experiments. This

could be due to the small sample sizes for these experiments. For this reason, emphasis was focussed only on the first three experiments.

The corresponding bootstrap standard error of the percentage reduction is shown in Table III.

The popper device as compared to other deterrents has generally smaller standard error for the percentage reduction. With a relatively higher value for the percentage reduction, as seen before, this suggests that the popper device performs better in deterring fish. The air bubble/popper device again follows the popper device with a small standard error. Meanwhile, the air bubble device shows far less consistent results with larger standard errors for 1985 than for 1986.

Tables IV and V give the 95% confidence intervals for the percentage reduction calculated by the standard normal and by the percentile method, respectively.

For the pneumatic popper device, the standard normal interval is close to the percentile interval. This suggests that the distribution of the bootstrap estimate for the percentage reduction for the popper is approximately normal. The intervals for the popper device and the air bubble/popper device do not contain zero and have positive end points. This suggests that these two devices are effective in excluding fish from the nuclear intakes. The air bubble device intervals show negative endpoints for 1985. In 1986, the endpoints were found to be positive, but with this inconsistency, nothing definite can be said about the air bubble device.

5. CONCLUSION

In evaluating the accuracy of the percentage reduction estimator, two measures were used: the standard error and the confidence interval. In the absence of a classical method for estimation, these measures were derived by the bootstrap method. Based on the results, the following statements can be made:

- The bootstrap method performs well for sample sizes greater than or equal to 13.
- The bootstrap mean for the percentage reduction is close to that of the percentage reduction value calculated for experiments with large sample size.
- Since the confidence intervals for the popper and the air bubble/popper devices do not contain zero and have positive endpoints, both deterrents are effective in deterring fish from the nuclear generating station intakes.

6. RECOMMENDATIONS

Based on the analyses done for this study, improvement of results could be made with the following suggestions:

a) Larger number of field trials should be conducted for experiments involving strobe lights.

b) For the results to be comparable, each of the experiments should be conducted at the same time of the day. This will minimize the variability in fish movements due to the time of day.

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TABLE I

Percentage Reduction Estimates

DEVICE	1985		1986	
	INSHORE	OFFSHORE	INSHORE	OFFSHORE
Popper	72.98	74.55	77.90	67.78
Airbubble/ Popper	45.24	74.20	74.77	82.40
Air bubble	-12.99	1.44	62.69	52.86
Strobe/ Air bubble	82.43	-8.24	-48.27	-32.43
Strobe/ Popper	-	-	70.39	45.81
Strobe	-	-	56.76	21.03
Strobe/Air bubble/ Popper	-	-	69.02	59.18

TABLE II

Bootstrap Mean of the Percentage Reduction Values

DEVICE	1985		1986	
	INSHORE	OFFSHORE	INSHORE	OFFSHORE
Popper	72.51	73.84	77.82	67.77
Airbubble/ Popper	44.46	72.53	75.43	82.41
Air bubble	-20.87	-2.88	60.70	52.0
Strobe/ Air bubble	82.04	-8.38	-42.21	-66.07
Strobe/ Popper	-	-	72.36	57.16
Strobe	-	-	63.55	43.44
Strobe/Air bubble/ Popper	-	-	71.12	72.29

TABLE III

Bootstrap Estimate of Standard Error
for Percentage Reduction

DEVICE	1985		1986	
	INSHORE	OFFSHORE	INSHORE	OFFSHORE
Popper	3.65	3.63	2.72	3.09
Airbubble/ Popper	17.32	6.83	3.87	2.94
Air bubble	48.57	14.8	12.02	7.04
Strobe/ Air bubble	4.94	14.52	26.88	38.33
Strobe/ Popper	-	-	14.82	10.74
Strobe	-	-	18.18	10.08
Strobe/Air bubble/ Popper	-	-	10.89	10.87

TABLE IV

95% Standard Normal Confidence Interval
for the Percentage Reduction

Note: l=lower limit u=upper limit

DEVICE		1985		1986	
		INSHORE	OFFSHORE	INSHORE	OFFSHORE
Popper	l	65.82	67.43	67.56	61.72
	u	80.15	81.66	78.24	73.83
Airbubble/ Popper	l	11.28	60.82	67.19	76.63
	u	79.20	87.58	82.35	88.17
Air bubble	l	-108.20	-27.57	39.14	39.05
	u	82.21	30.46	86.24	66.67
Strobe/ Air bubble	l	72.74	-36.69	-100.95	-107.55
	u	92.11	20.22	4.41	42.69
Strobe/ Popper	l	-	-	41.34	24.77
	u	-	-	99.44	66.85
Strobe	l	-	-	21.13	1.27
	u	-	-	92.40	40.79
Strobe/Air bubble/ Popper	l	-	-	47.68	37.88
	u	-	-	90.37	80.48

TABLE V

95% Confidence Interval Using Percentile Method
for the Percentage Reduction

Note: l=lower limit u=upper limit

DEVICE		1985		1986	
		INSHORE	OFFSHORE	INSHORE	OFFSHORE
Popper	l	63.04	65.31	64.69	61.66
	u	78.83	80.30	79.15	74.94
Airbubble/ Popper	l	3.31	60.18	66.95	76.09
	u	72.34	84.95	81.98	88.04
Air bubble	l	-124.86	-41.90	34.53	35.02
	u	56.16	20.21	81.95	62.85
Strobe/ Air bubble	l	73.38	-34.50	-76.17	-114.66
	u	91.58	19.82	7.47	29.93
Strobe/ Popper	l	-	-	44.46	24.46
	u	-	-	91.08	66.83
Strobe	l	-	-	-5.15	6.11
	u	-	-	78.73	47.38
Strobe/Air bubble/ Popper	l	-	-	43.35	35.27
	u			82.45	71.00

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